Application for United States Letters Patent
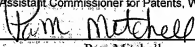
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METHOD FOR USING FIELD EMITTER ARRAYS IN CHEMICAL AND BIOLOGICAL HAZARD MITIGATION AND REMEDIATION

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METHOD FOR USING FIELD EMITTER ARRAYS IN CHEMICAL AND BIOLOGICAL HAZARD MITIGATION AND REMEDIATION

BACKGROUND OF THE INVENTION

1. FIELD OF THE INVENTION

This invention relates generally to methods of using field ionization devices, and, more particularly, to a method for using field emitter arrays to mitigate and remediate chemical and biological hazards.

2. DESCRIPTION OF THE RELATED ART

One of the biggest threats to the military and civilian populations of the United States and the rest of the world is the use of weapons of mass destruction based on biological and chemical warfare. Research emphasis has been on the detection of biological weapons because of the potentially catastrophic nature of the use of biological weapons. Until recently, there has been less emphasis on chemical weapons because of the large volume of material typically required to pose a major threat. However, there is growing concern that terrorists, foreign or domestic, could attack chemical plants producing ammonia (NH_3), chlorine (Cl_2), insecticides, and the like, where there are large volumes of highly toxic materials. Additionally, there are many manufacturing facilities (for example, manufacturing plants that typically use arsine, germane, diborane, and the like) where there are also large volumes of highly toxic materials already in place that may be vulnerable to terrorist attack. Because of these and other similar potentially disastrous scenarios, chemical weapons again are a major concern.

One of the problems with many of the current schemes for biological warfare defense (BWD) and chemical warfare defense (CWD) is that the defense systems are specific to certain chemicals or pathogens. Schemes that provide a more general defense such as high temperature catalytic oxidation or radio frequency (RF) plasma oxidation, require a large

amount of energy and power, and can produce harmful side-products. What is required is a defense system that can render harmless a large number of pathogens or compounds without producing harmful side-products. Another important element, especially for military applications is that the defense system should be portable and power-efficient enough so that the defense system can be used and implemented by individual soldiers and on small vehicles.

Biological and chemical warfare and/or terrorism and/or accidents are complicated by the fact that the delivery of the biological and/or chemical agents can be as simple as exposure of the pathogens and/or toxins to the atmosphere, resulting in potentially wide dispersal. Examples of these biological and/or chemical agents and/or pathogens and/or toxins may include Sarin ($(CH_3)_2 CHOP(O)FCH_3$), Soman ($(CH_3)_3 CHCH_3OP(O)FCH_3$), VX ($CH_3P(O)OC_2H_5SCH_2CH_2N(CH(CH_3)_2)_2$), and the like. The delivery method can be simple and extremely low cost. The effect of the biological and/or chemical agent can be immediate, or it can be delayed for days. Conventional devices are expensive, slow, consume a lot of power, and are bulky. These devices cannot operate in real-time and are not suitable for battlefield and forward deployment or emergency situations. Conventional approaches that are fast and that have the potential for real-time operation are extremely agent-specific and can be thwarted by developing new biological and chemical warfare agents. Hence, new approaches that have the potential of instantaneous detection in the field that are low cost, portable and consume very little power are desired.

The present invention is directed to overcoming, or at least reducing the effects of, one or more of the problems set forth above.

SUMMARY OF THE INVENTION

In one aspect of the present invention, a method is provided, the method comprising operating a field emitter array (FEA) to generate at least one of a high electric field and a high electron flux, and exposing the field emitter array (FEA) to at least one gas. The method

5   further comprises generating at least one radical species from the at least one gas exposed to the at least one of the high electric field and the high electron flux.

In another aspect of the present invention, a method is provided, the method comprising operating a low-power field emitter array (FEA) to generate at least one of a high electric field and a high electron flux, and exposing the low-power field emitter array (FEA)

10   to at least one gas. The method further comprises generating at least one radical species from the at least one gas exposed to the at least one of the high electric field and the high electron flux, and reacting the at least one radical species with at least one of a chemical and a biological toxin.

In yet another aspect of the present invention, a method is provided, the method

15   comprising operating a low-power field emitter array (FEA) to generate at least one of a high electric field and a high electron flux, and exposing the low-power field emitter array (FEA) to at least one of a chemical and a biological toxin. The method further comprises dissociating the at least one of the chemical and the biological toxin exposed to the at least one of the high electric field and the high electron flux.

20   In still yet another aspect of the present invention, a method is provided, the method comprising operating a field emitter array (FEA) to generate at least one of a high electric field and a high electron flux, and exposing the field emitter array (FEA) to at least one of a chemical and a biological toxin. The method further comprises ionizing the at least one of the chemical and the biological toxin exposed to the at least one of the high electric field and the

25   high electron flux.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention may be understood by reference to the following description taken in conjunction with the accompanying drawings, in which the leftmost significant digit(s) in the reference numerals denote(s) the first figure in which the respective reference numerals appear, and in which:

Figures 1-10 schematically illustrate various embodiments of a method according to the present invention; and, more particularly:

Figure 1 schematically illustrates a field effect display (FED) device representative of the principle of field emission;

Figure 2(a) schematically illustrates a small portion of a field emitter array (FEA) representative of those used in various of the illustrative embodiments of the present invention;

Figure 2(b) schematically illustrates a current/voltage (I-V) curve for a modern molybdenum-based field emitter array with 1 micrometer gate openings;

Figure 2(c) schematically illustrates Fowler-Nordheim tunneling for a modern molybdenum-based field emitter array with 1 micrometer gate openings;

Figure 3 schematically illustrates the difference between the ionization from a field emitter array (FEA) and the ionization from a conventional electron impact ionization source (EIIS), under controlled vacuum conditions;

Figure 4 schematically illustrates a comparison of the production of the atomic oxygen ion O^+ and molecular oxygen ion O_2^+ as a function of the molecular oxygen O_2 pressure;

Figure 5 schematically illustrates a comparison of the production of the atomic oxygen ion O^+ and molecular oxygen ion O_2^+ as a function of gate voltage V_g;

Figure 6 schematically illustrates a molybdenum-based field emitter array (FEA) exposed to helium, forming molybdenum-helide ions such as $MoHe^+$ and $MoHe_2^+$; and

Figures 7-10 schematically illustrate respective flow charts for various illustrative embodiments of a method according to the present invention.

While the invention is susceptible to various modifications and alternative forms, specific embodiments thereof have been shown by way of example in the drawings and are herein described in detail. It should be understood, however, that the description herein of specific embodiments is not intended to limit the invention to the particular forms disclosed, but on the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the appended claims.

DETAILED DESCRIPTION OF SPECIFIC EMBODIMENTS

Illustrative embodiments of the invention are described below. In the interest of clarity, not all features of an actual implementation are described in this specification. It will of course be appreciated that in the development of any such actual embodiment, numerous implementation-specific decisions must be made to achieve the developers' specific goals, such as compliance with system-related and business-related constraints, which will vary from one implementation to another. Moreover, it will be appreciated that such a development effort might be complex and time-consuming, but would nevertheless be a routine undertaking for those of ordinary skill in the art having the benefit of this disclosure.

In various illustrative embodiments of the present invention, high electric fields and electron flux densities generated by field emission arrays (FEAs) are used and employed for

biological warfare defense (BWD) and chemical warfare defense (CWD) systems. Additionally, various illustrative embodiments of the present invention enable the chemistry of complex molecules in very high electric fields and high electron flux densities to be exploited and used in reaction channels that are otherwise unavailable at typical thermal

5   energies.

Recent advances in field emission arrays (FEAs) now make it possible to utilize the chemistry of gaseous species in electric fields as high as about 10^7-10^8 V/cm and with average electron current densities as high as about an Amp/cm^2. These conditions can be achieved with voltages of less than or equal to about 100 V because the cathode-to-gate

10   distance in modern field emission arrays (FEAs) is less than or equal to about 1 micron (1 μm).

The principle of field emission may be illustrated by referring to a schematically illustrated field emission display (FED) device 100, as shown in Figure 1. The field emission display (FED) device 100 has a base plate 105 and a face plate 110 opposite to the base

15   plate 105. A number of cathode electrodes 115 are formed, in strips, for example, on the base plate 105. A number of anode electrodes 120 are formed, also in strips, for example, on the face plate 110. The strips of the anode electrodes 120 are disposed generally perpendicular to the strips of the cathode electrodes 115.

The anode electrodes 120 are formed on the face plate 110 on the surface opposite to

20   a viewing surface 125, and are made of indium oxide, tin oxide, indium-tin-oxide (ITO), and the like, which are transparent, conductive materials. A fluorescent material layer 130, having phosphors 135 disposed thereon, is deposited on the anode electrodes 120. Electrons ejected from tips 140 of emitters 145 on the base plate 105 collide with the phosphors 135 in the fluorescent material layer 130 and excite electrons in the phosphors 135 into higher energy

levels. As a result of the collision, light is emitted as the electrons in the phosphors 135 return to lower energy levels.

The base plate 105 is placed behind the face plate 110, away from the viewing surface 125, and is made of a semiconducting material or a ceramic or a glass. The cathode electrodes 115 formed on the base plate 105 are made of a highly doped semiconducting material such as polycrystalline silicon (polysilicon or poly) or a conductive metal. The emitters 145 are fabricated on the cathode electrodes 115 and are made of a metal such as molybdenum (Mo), tungsten (W), platinum (Pt), and the like. The emitters 145 may also be made of a semiconducting material such as silicon or silicon coated with titanium (Ti) or titanium nitride and/or any other convenient low work function material. The shape of the emitters 145 is generally conical, and electrons are emitted from the tips 140 of the emitters 145.

The emitters 145 may be separated from one another by dielectric materials 150 and gate electrodes 155 may be deposited on the dielectric materials 150. The gate electrodes 155 control an emission current 160 emitted from the emitters 145. Also, an opening 165 for evacuation is made at a desired portion of the base plate 105 where the cathode electrodes 115 are not deposited. An evacuation tube 170 is inserted into the opening 165 for evacuation (also known as "tubulation"). Gas residing in main space 175 is pumped out through the evacuation tube 170 and through the opening 165. When an appropriate low pressure is achieved, the evacuation tube 170 is sealed off.

The face plate 110 is attached facing the base plate 105 by spacers 180, with a desired separation distance d ranging from approximately 100 μm to 1000 μm, so that the fluorescent material layer 130 and the emitters 145 face each other and form the main space 175. The main space 175 is sealed off by firing the field emission display (FED) device 100 assembly after coating both side edges of the face plate 110 and base plate 105 with a frit seal 185.

The spacers 180 between the face plate 110 and the base plate 105 may have the shape of a wall at each of both edges of the face plate 110 and the base plate 105, and may have a cylindrical shape in between both edges of the face plate 110 and the base plate 105. The spacers 180 may be made of dielectric materials such as glass or polyimide, and the like.

5   The spacers 180 should have sufficient strength to withstand the load caused by the high pressure differential that exists between external atmospheric pressure and the pressure within the evacuated main space 175. The spacers 180 should also make the spacing in the display panel even, for consistent image resolution and brightness.

Also, the cathode electrodes 115 and the anode electrodes 120 may be extended to connect to an external circuit (not shown) placed outside the main space 175.

In one illustrative embodiment of an field emission display (FED) device 100, as described in Figure 1, if a negative voltage and a positive voltage are respectively applied to one of the cathode electrodes 115 and a corresponding one of the anode electrodes 120 by an external circuit, an electric field is established between that cathode electrode 115 and that anode electrode 120. Electrons are able to be emitted from the emitters 140 where such an electric field is formed. The voltage on the anode electrodes 120 may not cause field emission, since the electric field strength of the electric field established between a cathode electrode 115 and the corresponding anode electrode 120 may not be large enough. However, the anode electrodes 120 may attract electrons once emitted from the corresponding cathode electrodes 115.

20   Positive voltages are applied to selected ones of the gate electrodes 155 on the base plate 105 to make the emission of electrons from the corresponding emitters 145 easier. The electrons emitted from the emitters 145 are accelerated by the anode electrodes 120 and collide with the phosphors 135 of the fluorescent material layer 130. Then, the fluorescent

material layer 130 emits light in the appropriate pattern for forming a picture viewable on the viewing surface 125.

The field emission display (FED) structure described in detail above, which is called triode-type, has conic-shaped emitters 145 made of metal, for example, and gate electrodes 155. Alternatively, a thin film diode-type field emission display (FED) structure is available where emitters are made of diamond thin-film and separate gate electrodes are not needed.

More generally, Figure 2(a) shows a schematic illustration of a small portion of a field emitter array (FEA) representative of those used in various of the illustrative embodiments of the present invention. A cathode electrode 215 and an anode electrode 220 are disposed opposite each other, and may be made of indium oxide, tin oxide, indium-tin-oxide (ITO), and the like, for example, which are transparent, conductive materials. In alternative illustrative embodiments, the cathode electrode 215 and/or the anode electrode 220 may be made of highly doped polysilicon or a conductive material such as platinum (Pt), gold (Au), tin oxide (SnO_2), ITO, zinc oxide (ZnO), and the like. Electrons 260 are emitted from tips 240 of emitters 245 disposed on the cathode electrode 215. The emitters 245 are fabricated on the cathode electrodes 215 and are made of a metal such as molybdenum (Mo), tungsten (W), platinum (Pt), and the like. The emitters 245 may also be made of a semiconducting material such as silicon or silicon coated with titanium (Ti) or titanium nitride and/or any other convenient low work function (low Φ) material. For example, carbon nanotubes may also be used for the emitters 245. The shape of the emitters 245 is generally conical, and electrons 260 are emitted from the tips 240 of the emitters 245.

The emitters 245 may be separated from one another by dielectric materials 250 and gate electrodes 255 may be deposited on the dielectric materials 250. The gate electrodes 255 control a field emission current of the electrons 260 emitted from the emitters 245. The

electric field strengths at the tips 240 of the emitters 245 may be as high as about 10^7-10^8 V/cm. The field emission current of the electrons 260 may have an average electron current density (flux) as high as about an Amp/cm^2. These conditions may be achieved with a gate voltage V_g of less than or equal to about 100 V because the thickness t of

5   the dielectric materials 250, in a field emission array (FEA), according to various illustrative embodiments of the present invention, is less than or equal to about 1 micron (1 μm). The thickness t of the dielectric materials 250 may also be substantially similar to the cathode-to-gate distance for gate openings of about 1 micron (1 μm).

In various alternative illustrative embodiments, a field emitter array (FEA) may be operated with a gate voltage V_g of less than or equal to about 1000 V with single wire emitters 245. In various alternative illustrative embodiments, a field emitter array (FEA) may be operated with the cathode-to-gate distance and/or gate openings in a range of about 1 micron (1 μm) to about 1 millimeter (1 mm).

The cathode electrode 215 and the anode electrode 220 may be extended to connect to an external circuit, as indicated schematically in Figure 2(a). A positive gate voltage V_g may be applied to the gate electrodes 255, while the cathode electrode 215 may be grounded, leading to the field emission current of the electrons 260. A positive anode voltage V_a may be applied to the anode electrode 220, attracting the field emission current of the electrons 260, as measured by an ammeter A, measuring an anode current I_a, as shown graphically in

20   Figure 2(b). Figure 2(b) shows a current/voltage (I-V) curve for a modern molybdenum-based field emitter array. The gate voltage V_g, measured in volts (V), is plotted along the horizontal axis against anode current I_a, measured in micro-Amperes (μA), plotted along the vertical axis.

Ionizers based on electron impact ionization use the electrons 260 emitted from the

25   field emission array (FEA). The array of sharp tips 240 which serve as the high flux

electron 260 source as a result of Fowler-Nordheim tunneling, as shown graphically in Figure 2(c). The Fowler-Nordheim tunneling anode current I_a, may be expressed as a function of the gate voltage V_g, and the work function Φ of the emitters 245 fabricated on the cathode electrode 215 as follows: $I_a = aV_g^2 \exp\left(-b\Phi^{3/2}/V_g\right)$, where a and b have the appropriate units. For example, a may be expressed in micro-Amperes per volt-squared ($\mu A/V^2$), and b may be expressed in reciprocal square-root volts ($V^{-1/2}$), where the anode current I_a is expressed in micro-Amperes (μA), and the gate voltage V_g and the work function Φ of the emitters 245 are both expressed in volts (V). As shown in Figure 2(c), the reciprocal of the gate voltage V_g, measured in volts (V), is plotted along the horizontal axis against the natural logarithm of the anode current I_a divided by a times the square of the gate voltage V_g, $I_a/a(V_g)^2$, plotted along the vertical axis. As shown in Figure 2(c), the slope of the line is proportional to the cube of the square-root ($\Phi^{3/2}$) of the work function Φ. The extraction efficiency can be controlled by the gate electrode 255.

In an electron impact ionization source (EIIS), the emitted electrons are accelerated to very high voltages. When the electrons collide with neutral gas atoms and/or molecules, the electrons transfer energy to the neutral gas atoms and/or molecules, leading to ionization of the gas atoms and/or molecules. The process can result in the fragmentation of the gas molecules, leading to several by-products with specific signatures. The ions may be spectrally separated by ion optics and detected by mass spectrometry. A field emission array (FEA) is an efficient low voltage and low-power electron source for a field ionization system.

An example of the effect of high electric fields and/or high electron flux densities on a simple molecule is the ionization of molecular oxygen, O_2, under these extreme conditions. In a conventional electron impact ionization source (EIIS), the predominant species formed is the molecular oxygen ion, O_2^+. In the presence of an "active" field emitter array (FEA),

according to various illustrative embodiments of the present invention, the predominant species that is formed is the atomic oxygen ion, O^+.

Figure 3 shows the difference between the ionization from a field emitter array (FEA) and the ionization from a conventional electron impact ionization source (EIIS), under controlled vacuum conditions. The time, measured in seconds (sec), is plotted along the horizontal axis against an ion signal, measured in arbitrary units (arb. Units), plotted along the vertical axis. The pressure of the molecular oxygen O_2 for both sets of measurements is about 10^{-9} Torricellis (Torr), $P(O_2) = 10^{-9}$ Torr.

In Figure 3(a), the field emitter array (FEA) is initially exposed to molecular oxygen O_2 with the gate voltage off ($V_g = 0$) to exhibit a reference signal (a partial pressure measurement) molecular oxygen of O_2. Subsequently, the gate voltage is increased to about 70 V ($V_g = 70$ V) to "activate" the field emitter array (FEA), thus rendering field emitted electrons (similar to the field emitted electrons 260, as shown in Figure 2(a)), under high electric field (electric field strength in a range of about 10^7-10^8 V/cm) conditions. The dominant species observed is the atomic oxygen ion O^+, instead of the molecular oxygen ion O_2^+.

By way of contrast, Figure 3(b) presents the results of a substantially similar experiment with a conventional electron impact ionization source (EIIS) configuration, where the molecular oxygen ion O_2^+ is the dominant species observed. The conventional electron impact ionization source (EIIS) ionizer in this experiment was "off" for about 100 sec, "on" for the next about 300 sec, and then "off" again thereafter. Given the substantially identical controlled vacuum conditions in which these measurements were obtained, it is unlikely that the molecular oxygen ion O_2^+ is scavenged by the activated field emitter array (FEA) to result in the observed O^+ abundance. Rather, in the presence of an activated field emitter array

(FEA), according to various illustrative embodiments of the present invention, the predominant species formed is the atomic oxygen ion O^+.

Figure 4 shows a comparison of the production of the atomic oxygen ion O^+ and molecular oxygen ion O_2^+ as a function of the molecular oxygen O_2 pressure. The pressure
5     $P(O_2)$ of the molecular oxygen O_2, measured in Torr, ranging from about $P(O_2) = 2 \times 10^{-10}$ Torr to about $P(O_2) = 1 \times 10^{-6}$ Torr, is plotted along the horizontal axis against an ion signal$\times 10^{-8}$, measured in arbitrary units (arb. units), plotted along the vertical axis.

The atomic oxygen ion O^+ species remains dominant throughout the pressure regime examined. Moreover, ionized molybdenum (Mo^+ and Mo^{++}) species are also observed at
10   higher molecular oxygen O_2 partial pressures, indicating that the tip undergoes modification, probably from the atomic oxygen ion O^+ species exposure, under active conditions of an activated field emitter array (FEA), according to various illustrative embodiments of the present invention.

Figure 5 shows a comparison of the production of the atomic oxygen ion O^+ and
15   molecular oxygen ion O_2^+ as a function of gate voltage V_g. The gate voltage V_g, measured in volts (V), is plotted along the horizontal axis against an ion signal$\times 10^{-7}$, measured in arbitrary units (arb. units), plotted along the vertical axis. In Figure 5(a), the pressure $P(O_2)$ of the molecular oxygen O_2, measured in Torr, is about $P(O_2)=1 \times 10^{-8}$ Torr. In Figure 5(b), the pressure $P(O_2)$ of the molecular oxygen O_2, measured in Torr, is about $P(O_2)=1 \times 10^{-9}$ Torr.
20   Again, the atomic oxygen ion O^+ is observed as the dominant species above $V_g = 50$ V. However, the comparison of the production of the atomic oxygen ion O^+ and molecular oxygen ion O_2^+ as a function of gate voltage V_g is complicated by the fact that by raising the gate voltage V_g, the electric field strength E_g, and the Fowler-Nordheim tunneling anode current density J_a (where J_a = the Fowler-Nordheim tunneling anode current I_a per unit area,
25   is essentially the electron emission 260 flux, in Amperes per square centimeter, for example),

both increase concomitantly. Depending on the process for the formation of the atomic

oxygen ion O^+, either of the parameters, the value of the electric field strength E_g, and/or the

value of the Fowler-Nordheim tunneling anode current density J_a, may contribute to

enhanced formation of the atomic oxygen ion O^+.

5   Interestingly, when a molybdenum-based field emitter array (FEA) is exposed to

helium, molybdenum-helide ions such as $MoHe^+$ and $MoHe_2^+$ may be formed, as shown in

Figure 6. The time, measured in seconds (sec), is plotted along the horizontal axis against an

ion signal, measured in arbitrary units (arb. Units), plotted along the vertical axis. The

molybdenum-based field emitter array (FEA) in this experiment was "off" for about 70 sec,

10   "on" for the next about 110 sec, and then "off" again thereafter.

        Although the observation of molybdenum-helides was first reported by E. W.

Mueller, in *Adv. Electr. Electron Phys.*, Vol. 13 (1960), at page 83, in early single-tip Field

Ion Microscopy (FIM) studies, the poor ion counting statistics of the technique resulted in

debates over the data for many years thereafter. The use of a field emission array (FEA) with

15   about 10^5 tips 240 (Figure 2(a)), improves the sensitivity to such reaction channels, and thus

permits a wider range of possibilities for observation and study of molybdenum-helide ions

such as $MoHe^+$ and $MoHe_2^+$. It is believed that the lifetimes of the helide ion species, such as

$MoHe^+$ and $MoHe_2^+$ is long enough to allow the molecular species to travel approximately

20 cm from the field emitter cathode 215 to a quadrupole mass spectrometer (not shown),

20   where the ionic species may be detected.

        As shown in Figure 7, in various illustrative embodiments of the present invention, a

field emitter array (FEA), similar to the field emitter array (FEA) schematically illustrated in

Figure 2(a), is used to generate high electric fields and/or electron fluxes to generate a radical

species resultant from the exposure of the electrically biased field emitter array (FEA) to

25   candidate gases (O_2 being an example of a candidate gas). As shown in Figure 7, a

method 700 may be provided, the method 700 comprising operating a field emitter array (FEA) to generate at least one of a high electric field and/or a high electron flux, as shown in box 710.

Operating the field emitter array (FEA) to generate a high electric field and/or a high

5 electron flux, as shown in box 710, may comprise operating the field emitter array (FEA) to generate an electric field having a field strength in a range of about 10^7-10^8 V/cm. Operating the field emitter array (FEA) to generate a high electric field and/or a high electron flux, as shown in box 710, may comprise operating the field emitter array (FEA) to generate an electron flux in a range of about 0.5-2.0 Amp/cm^2. Operating the field emitter array (FEA) to

10 generate a high electric field and/or a high electron flux, as shown in box 710, may comprise operating the field emitter array (FEA) with voltages of no more than about 100 V. In various alternative illustrative embodiments, operating the field emitter array (FEA) to generate a high electric field and/or a high electron flux, as shown in box 710, may comprise operating the field emitter array (FEA) with voltages of no more than about 1000 V with single wire

15 emitters.

The method 700 further comprises exposing the field emitter array (FEA) to at least one gas, as shown in box 720. Exposing the field emitter array (FEA) to at least one gas, as shown in box 720, may comprise exposing the field emitter array (FEA) to molecular oxygen (O_2). The method 700 also comprises generating at least one radical species from the gas

20 exposed to the high electric field and/or the high electron flux, as shown in box 730.

As shown in Figure 8, in various alternative illustrative embodiments of the present invention, a low-power field emitter array (FEA), similar to the field emitter array (FEA) schematically illustrated in Figure 2(a), is used to generate radical species to be made available to subsequently dissociate chemical or biological toxins and render them harmless

25 or suitable for further reduction to a harmless state. As shown in Figure 8, a method 800 may

be provided, the method 800 comprising operating a low-power field emitter array (FEA) to generate at least one of a high electric field and/or a high electron flux, as shown in box 810.

Operating the low-power field emitter array (FEA) to generate a high electric field and/or a high electron flux, as shown in box 810, may comprise operating the low-power field emitter array (FEA) to generate an electric field having a field strength in a range of about 10^7-10^8 V/cm. Operating the low-power field emitter array (FEA) to generate a high electric field and/or a high electron flux, as shown in box 810, may comprise operating the low-power field emitter array (FEA) to generate an electron flux in a range of about 0.5-2.0 Amp/cm^2. Operating the low-power field emitter array (FEA) to generate a high electric field and/or a high electron flux, as shown in box 810, may comprise operating the low-power field emitter array (FEA) with voltages of no more than about 100 V. In various alternative illustrative embodiments, operating the field emitter array (FEA) to generate a high electric field and/or a high electron flux, as shown in box 810, may comprise operating the field emitter array (FEA) with voltages of no more than about 1000 V with single wire emitters.

The method 800 further comprises exposing the low-power field emitter array (FEA) to at least one gas, as shown in box 820. Exposing the low-power field emitter array (FEA) to at least one gas, as shown in box 820, may comprise exposing the low-power field emitter array (FEA) to molecular oxygen (O_2).

The method 800 still further comprises generating at least one radical species from the gas exposed to the high electric field and/or the high electron flux, as shown in box 830. The method 800 also comprises reacting the radical species with at least one of a chemical and/or a biological toxin, as shown in box 840.

As shown in Figure 9, in various alternative illustrative embodiments of the present invention, a low-power field emitter array (FEA), similar to the field emitter array (FEA)

schematically illustrated in Figure 2(a), is used to dissociate chemical and/or biological toxins

directly and render them harmless and/or suitable for further reduction to a harmless state. As

shown in Figure 9, a method 900 may be provided, the method 900 comprising operating a

low-power field emitter array (FEA) to generate at least one of a high electric field and/or a

5   high electron flux, as shown in box 910.

Operating the low-power field emitter array (FEA) to generate a high electric field

and/or a high electron flux, as shown in box 910, may comprise operating the low-power

field emitter array (FEA) to generate an electric field having a field strength in a range of

about 10^7-10^8 V/cm. Operating the low-power field emitter array (FEA) to generate a high

10   electric field and/or a high electron flux, as shown in box 910, may comprise operating the

low-power field emitter array (FEA) to generate an electron flux in a range of

about 0.5-2.0 Amp/cm^2. Operating the low-power field emitter array (FEA) to generate a high

electric field and/or a high electron flux, as shown in box 910, may comprise operating the

low-power field emitter array (FEA) with voltages of no more than about 100 V. In various

15   alternative illustrative embodiments, operating the field emitter array (FEA) to generate a

high electric field and/or a high electron flux, as shown in box 910, may comprise operating

the field emitter array (FEA) with voltages of no more than about 1000 V with single wire

emitters.

Operating the low-power field emitter array (FEA) to generate a high electric field

20   and/or a high electron flux, as shown in box 910, may comprise operating the low-power

field emitter array (FEA) with a cathode-to-gate distance of not more than

about 1 micron (1μm). In various alternative illustrative embodiments, operating the

low-power field emitter array (FEA) to generate a high electric field and/or a high electron

flux, as shown in box 910, may comprise operating the low-power field emitter array (FEA)

with a cathode-to-gate distance and/or gate openings in a range of about 1 micron (1 μm) to about 1 millimeter (1 mm).

The method 900 further comprises exposing the low-power field emitter array (FEA) to at least one of a chemical and/or a biological toxin, as shown in box 920. The method 900 also comprises dissociating the chemical and/or the biological toxin exposed to the high electric field and/or the high electron flux, as shown in box 930.

As shown in Figure 10, in various illustrative embodiments of the present invention, a field emitter array (FEA), similar to the field emitter array (FEA) schematically illustrated in Figure 2(a), is used as an ionization source to facilitate the detection of biological and/or chemical toxins. As shown in Figure 10, a method 1000 may be provided, the method 1000 comprising operating a field emitter array (FEA) to generate at least one of a high electric field and/or a high electron flux, as shown in box 1010.

Operating the low-power field emitter array (FEA) to generate a high electric field and/or a high electron flux, as shown in box 1010, may comprise operating the low-power field emitter array (FEA) to generate an electric field having a field strength in a range of about 10^7-10^8 V/cm. Operating the low-power field emitter array (FEA) to generate a high electric field and/or a high electron flux, as shown in box 1010, may comprise operating the low-power field emitter array (FEA) to generate an electron flux in a range of about 0.5-2.0 Amp/cm². Operating the low-power field emitter array (FEA) to generate a high electric field and/or a high electron flux, as shown in box 1010, may comprise operating the low-power field emitter array (FEA) with voltages of no more than about 100 V. In various alternative illustrative embodiments, operating the field emitter array (FEA) to generate a high electric field and/or a high electron flux, as shown in box 1010, may comprise operating the field emitter array (FEA) with voltages of no more than about 1000 V with single wire emitters.

Operating the low-power field emitter array (FEA) to generate a high electric field and/or a high electron flux, as shown in box 1010, may comprise operating the low-power field emitter array (FEA) with a cathode-to-gate distance of not more than about 1 micron (1μm). In various alternative illustrative embodiments, operating the

5 low-power field emitter array (FEA) to generate a high electric field and/or a high electron flux, as shown in box 1010, may comprise operating the low-power field emitter array (FEA) with a cathode-to-gate distance and/or gate openings in a range of about 1 micron (1 μm) to about 1 millimeter (1 mm).

The method 1000 further comprises exposing the field emitter array (FEA) to at least

10 one of a chemical and/or a biological toxin, as shown in box 1020. The method 1000 also comprises ionizing the chemical and/or the biological toxin exposed to the high electric field and/or the high electron flux, as shown in box 1030.

Most conventional biological and chemical warfare agent detection systems depend on a two-pass detection system. An ultraviolet (UV) fluorescence excitation/detection system

15 is typically used to scan for a non-specific trigger to distinguish between biological and non-biological matter. This is followed by a time-of-flight (TOF) mass spectrometer that provides specific discrimination between various biological and chemical agents. These conventional biological and chemical warfare agent detection systems are typically rack mounted and may fill up a room, or at least a small vehicle. These conventional biological

20 and chemical warfare agent detection systems consume significant power and require human interaction. Consequently, these conventional biological and chemical warfare agent detection systems are unsuitable for battlefield and emergency operations.

A study of conventional systems that are based on mass spectrometry suggests that there is a need for more compact, more sensitive, more stable and lower power methods of

25 ionizing the pathogens and/or agents. As described herein, we have developed very compact

and low-power detection systems with high sensitivity. Another issue that has plagued existing conventional systems is the reliability and the stability of the ionization sources. The ionization source is important to the development of compact, low-power, low cost and high sensitivity biological and chemical warfare agent detection systems. Also important is the use

5 of field emitter arrays for the destruction of biological and chemical agents through the use of high field chemistry.

As described herein, we have developed new approaches to ionizing the biological and/or chemical agents with extremely low-power, low voltage, small size and high sensitivity suitable for compact instruments that can be deployed in the field. In order to use a

10 field emitter array (FEA) for a field ionization source, it is desirable that such a field emitter array (FEA) operate robustly in a variety of environments.

Any of the above-disclosed embodiments of a method according to the present invention enables the size of biological and chemical toxin mitigation and/or remediation and/or detection systems to be reduced to tabletop and/or shoebox sizes. Any of the

15 above-disclosed embodiments of a method according to the present invention enables such a system to be the size of the "Palm Pilot®" so that it may be carried by an individual soldier. Such a system that is more compact, operates in real-time and consumes less power, and could be deployed in remote locations, on a soldier, on an intelligent robot, or on an unmanned aerial vehicle (UAV) that is able to communicate with a base station. Corrective

20 actions could be initiated with information supplied by such a system.

The particular embodiments disclosed above are illustrative only, as the invention may be modified and practiced in different but equivalent manners apparent to those skilled in the art having the benefit of the teachings herein. Furthermore, no limitations are intended to the details of construction or design herein shown, other than as described in the claims

25 below. It is therefore evident that the particular embodiments disclosed above may be altered

or modified and all such variations are considered within the scope and spirit of the invention. In particular, every range of values (of the form, "from about a to about b," or, equivalently, "from approximately a to b," or, equivalently, "from approximately a-b") disclosed herein is to be understood as referring to the **power set** (the set of **all** subsets) of the respective range

5   of values, in the sense of Georg Cantor. Accordingly, the protection sought herein is as set forth in the claims below.